WRF Four-Dimensional Data Assimilation (FDDA)

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NCAS/NCAR Tutorial, Durham, UK
October 2017

FDDA

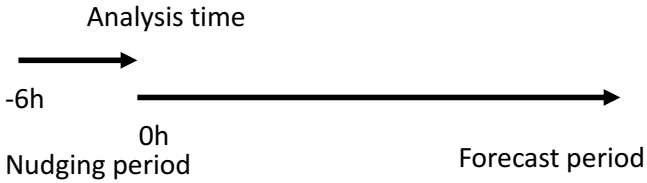
- Method of nudging model towards observations or analysis (gridded data)
- May be used for
  - Dynamic initialization (pre-forecast period)
  - Create 4-dimensional meteorological datasets (e.g. for air-quality models)
  - Boundary conditions (with outer domain nudged towards analysis)

Method

- Model is run with extra nudging terms for horizontal winds, temperature and water vapor
- In analysis nudging, these terms nudge point-by-point to a 3d space- and time-interpolated analysis field
- In obs-nudging, points near observations are nudged based on model error at obs site
- The nudging is a relaxation term with a user-defined time scale around an hour or more
- Nudging will work with nesting and restarts

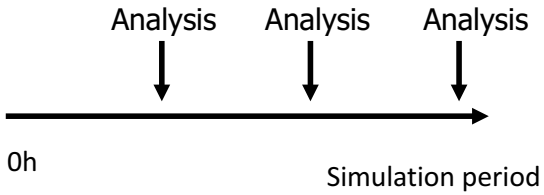
Dynamic Initialization

- Model domains are nudged towards analysis in a pre-forecast period of 6-12 hours
- This has benefit of smooth start up at forecast time zero



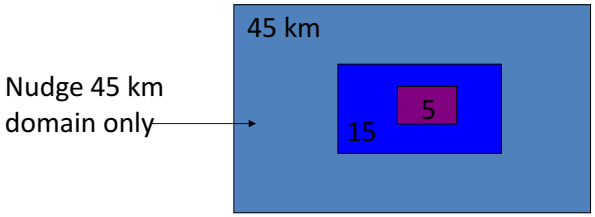
Four-Dimensional Met Analysis

- Produces analyses between normal analysis times
- High-resolution balanced and mass-continuity winds can be output to drive off-line air quality models



Boundary Conditions

- Nudge an outer domain towards analysis through forecast
- This has benefit of providing smoother boundary conditions to domain of interest than if 15 km domain is the outer domain with interpolated-analysis boundary conditions



FDDA Methods

- Three Methods
  - Grid or analysis nudging (suitable for coarse resolution)
  - Observation or station data nudging (suitable for fine-scale or asynoptic obs)
  - Spectral nudging on selective scales
- Nudging can be applied to winds, temperature, water vapor (first two methods), and geopotential (spectral)

Note: nudging terms are fake sources, so avoid FDDA use in dynamics or budget studies. Also data may be linearly interpolated.

Analysis Nudging (grid_fdda=1)

- Each grid-point is nudged towards a value that is time-interpolated from analyses

From MM5: Stauffer and Seaman (1990 MWR, 1994 JAM)

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot W_\alpha \cdot \epsilon_\alpha(\mathbf{x}) \cdot p^*(\hat{\alpha}_0 - \alpha)$$

In WRF p* is μ and α is *u,v,T or q*

F includes all the regular WRF terms

Analysis Nudging

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot W_\alpha \cdot \epsilon_\alpha(\mathbf{x}) \cdot p^*(\hat{\alpha}_0 - \alpha)$$

- G is nudging inverse time scale
- W is vertical weight (upper air and surface)
- ε is a horizontal weight for obs density (not implemented)

Analysis Nudging

- 3d analysis nudging uses the WRF input fields at multiple times that are put in wrffdda_d01 file by program real when run with grid_fdda=1
  - With low time-resolution analyses, it is recommended not to use 3d grid-nudging in the boundary layer, especially for temperature
- Surface (2d) analysis nudging
  - Nudges surface and boundary layer only

Analysis-Nudging namelist options

Can choose

- Frequency of nudging calculations (fgdt in minutes)
- Nudging time scale for each variable (guv, gt, gq in inverse seconds)
- Which variables not to nudge in the PBL (if_no_pbl_nudging_uv, etc.)
- Model level for each variable below which nudging is turned off (if_zfac_uv, k_zfac_uv, etc.)
- Ramping period over which nudging is turned off gradually (if_ramping, dt_ramp_min)

Surface Analysis Nudging

- 2d (surface) nudging (grid_fdda=1 and grid_sfdda=1) for surface analyses
  - wrfsfdda_d01 file created by obsgrid.exe
  - Weights given by guv_sfc, gt_sfc, and gq_sfc
  - Note: grid_fdda=1 must be used to activate this. If upper-air nudging not wanted, set upper weights guv, gt, gq =0.
- In Version 3.8 we have FASDAS (grid_sfdda=2)
  - Flux-Adjusted Surface Data Assimilation System
  - This is a special option to also correct the soil state
    - Only works with YSU PBL and Noah LSM

Spectral Nudging (grid_fdda=2)

- Spectral nudging does 3d nudging of only selected larger scales using gridded fields
  - Allows model small scales to evolve with no nudging
- This may be useful for controlling longer wave phases for long analysis-driven simulations (e.g. months to years)
  - Compensates for error due to low-frequency narrow lateral boundaries
  - Top wavenumber nudged is selected in namelist (xwavenum, ywavenum, e.g. =3)
    - Typically choose so that (domain size)/(wavenumber)=~1000 km in each direction
  - Nudges u, v, temperature, geopotential (not q)
  - Can nudge in all levels or use ramp above a specified model level (if_zfac_ph, k_zfac_ph, dk_zfac_ph, etc.)

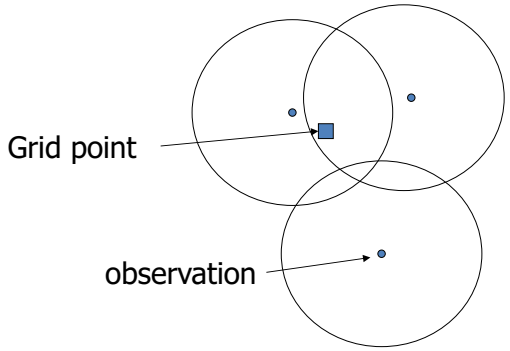
Obs Nudging (obs_nudge_opt=1)

- Each grid point is nudged using a weighted average of differences from observations within a radius of influence and time window

$$\frac{\partial p^* \alpha}{\partial t} = F(\alpha, \mathbf{x}, t) + G_\alpha \cdot p^* \frac{\sum_{i=1}^{N} W_i^2(\mathbf{x}, t) \cdot \gamma_i \cdot (\alpha_o - \hat{\alpha})_i}{\sum_{i=1}^{N} W_i(\mathbf{x}, t)}$$

$$W(\mathbf{x}, t) = w_{xy} \cdot w_\sigma \cdot w_t$$

Obs Nudging



Note: errors at obs sites are weighted by distance for nudging

Obs Nudging

$$w_{xy} = \frac{R^2 - D^2}{R^2 + D^2} \qquad 0 \le D \le R$$

$$w_{xy} = 0 \qquad D > R,$$

- R is radius of influence
- D is distance from ob modified by elevation difference

Obs Nudging

$$w_t = 1 \qquad |t - t_0| < \tau/2$$

$$w_t = \frac{\tau - |t - t_0|}{\tau/2} \qquad \tau/2 \le |t - t_0| \le \tau$$

- t is the specified time window for the obs
- This is a function that ramps up and down

Obs Nudging

- w_s is the vertical weighting – usually the vertical influence is set small (0.005 eta-difference) so that data is only assimilated on its own eta level
- obs input file is a special ascii file (OBS_DOMAIN101) with obs sorted in chronological order
  - Each record is the obs (u, v, T, Q) at a given model position and time
  - Utility programs exist to convert data to this format from other common formats
  - In V3.1 obsgrid.exe can create this file from standard observations that are in little_r format

Obs-Nudging namelist options

Can choose

- Frequency of nudging calculations (iobs_ionf)
- Nudging time scale for each variable (obs_coef_wind, etc.)
- Horizontal and vertical radius of influence (obs_rinxy, obs_rinsig)
- Time window (obs_twindo)
- Ramping period over which nudging is turned off gradually (obs_idynin, obs_dtramp)

Vertical weighting functions

- Added flexibility options for advanced usage of obs-nudging with surface observations (switches in run/README.namelist, e.g. obsnudgezfullr1_uv, etc.)
  - These allow specifying how variables are nudged in a profile with their full weight and/or ramp down function relative to the surface or PBL top in different regimes (stable or unstable).
  - Defaults are set to reasonable values, so these can be left out of namelist unless needed.

FDDA Summary

- FDDA grid nudging is suitable for coarser grid sizes where analysis can be better than model-produced fields
- Obs nudging can be used to assimilate asynoptic or high-frequency observations
- Grid and obs nudging can be combined
- Spectral nudging may be used to control large scale flows
- FDDA has fake sources and sinks and so should not be used on the domain of interest and in the time period of interest for scientific studies and simulations